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TRANSITIONAL HEAT REGIME REALIZABLE ON ACCOUNT OF BEAM ENERGY TRANSFER IN SCATTERING MEDIA.

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13. ABSTRACT

In numerous dispersion media (powders of different materials, hydrosol and aerosol systems) where the contact between the isolated particles is small or non existent, the heat regime is realized basically on account of the transfer of radical energy. An equation of thermal conductivity is presented for the above.

This equation in combination with the transfer equation, is written out for the spectral density of space illumination, allows in principle to research the transitional heat regime. However, the analytical solution of the problem is only possible for a limited number of situations. Some of these are examined.

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NOTICE

TRANSITIONAL HEAT REGIME REALIZABLE ON ACCOUNT OF BEAM ENERGY TRANSFER IN SCATTERING MEDIA.

(presented by the Academician B.I. Stepanov, of the Belorussian SSR Academy of Sciences).

In numerous dispersion media (powders of different materials, hydrosol and aerosol systems) where the contact between the isolated particles is small or non existent, the heat regime is realized basically on account of the transfer of radial energy. In this case, as it is easy to indicate, the equation of the thermal conductivity appears as :

$$\frac{dT(x, y, z, t)}{dt} \quad \frac{1}{c\rho}\int_{\nu}\left\{E_\nu(x, y, z, t) - \frac{v}{2}U_\nu[x, y, z, T(t)]\right\}k(\nu)\,d\nu. \qquad (1)$$

Here T (x,y,z,t) - is the temperature at the time moment t at a point, whose position in space is determined by the coordinators x, y, z; E_ν - is the spectral density of the space lighting ; U_ν - is the density of the balanced irradiation calculated on a unit spectral interval ; v is the speed of light in the medium; c and p represent the average specific thermal capacity and the density of the media ; k(v) is the indicator of absorption * ; v is the frequency of the electromagnetic radiation.

The equation (1) in combination with transfer equation (1) , is written out for the spectral density of space illumination E_ν , allows in principle to research the transitional heat regime. However, the analytical solution of the problem is only possible for a limited number of situations. We shall examine some of them .

1) Let us assume the following, at any point of the space E_ν vU_ν . This is possible at the initial moment of time when the medium is illuminated with a powerful radiation and has a low temperature. Then E_ν is determined solely by exterior illumination conditions, does not depend on time , and instead of(1) one car write :

$$\frac{dT(x, y, z, t)}{dt} \quad \frac{1}{c\rho}\int_{\nu}E_\nu(x, y, z)\,k(\nu)\,d\nu. \qquad (2)$$

The solution of the equation (2) appears as following :

$$T(x, y, z\ t) \quad \frac{t}{c\rho}\int_{\nu}E_\nu(x, y, z)\,k(\nu)\,d\nu \quad T_0(x, y, z). \qquad (3)$$

where T_0 (x, y, z,) is the early temperature distribution. In this way, the heating of the medium in the preliminary stage occurs according to the linear rule. The speed of temperature increase in proportion to the increase of radiation absorption and to the decrease of heat capacity and medium density. With the passing of time, the relative temperature distribution over the space changes.

II - Let us assume the existence of a space illumination at any point of the medium, caused by outer radiation and own heat background, considerably less space illumination of a balanced radiation, corresponding to the temperature T, t.e. $E_v \ll vU_v$. Such a condition can be realized in a very heated medium of small dimensions. Instead of equation (1) it should be written as follows :

$$\frac{dT(x,\ y,\ z,\ t)}{dt} = -\frac{v}{2c\rho}\int_{v} U_{v}\left[x,\ y,\ z,\ T(t)\right] k(v)\,dv. \tag{4}$$

Sufficiently simple analytical solutions of equation (4), which describes the process of cooling in the medium, one can obtain in the following cases :

Size $\frac{hv}{kT} \ll 1$ (h and k - Plank and Bolzmann constants)

In such circumstances, the radiation is described by the Raileigh Jinks formula, and (4)
it looks like :

$$\frac{dT}{T} = -\frac{4\pi k dt}{c\rho v^2}\int k(v)\,v^2 dv. \tag{5}$$

Solution (5) for the

$$T(x,\ y,\ z,\ t = 0) = T_0(x,\ y,\ z)$$

will be

$$T(x,\ y,\ z,\ t) = T_0(x,\ y,\ z)\,c^{-at},$$

where

$$a = \frac{4\pi k}{c\rho v^2}\int_{v} k(v)\,v^2 dv. \tag{6}$$

In the given case, the relative distribution of temperature over the space does not change.

2 - The absorption indicator k does not depend on the light frequency v . In this case, on the basis of the Stephan Bolzmann rule, instead of equation (4) it is possible to write out :

$$\frac{dT}{dt} = -\frac{2k\sigma}{c\rho}T^4 \tag{7}$$

($\sigma = 5{,}7 \cdot 10^{-12}$ *вт/см² град⁴* –

Stephan Botzmann constant)

Solution (7) appears as follows :

$$T^3(x,\ y,\ z,\ t) = \frac{T_0^3(x,\ y,\ z)}{\frac{6k\sigma}{c\rho} T_0^3(x,\ y,\ z)\,t + 1}. \tag{8}$$

3) Absorption, and, accordingly, the heat emanation occurs within the narrow spectral interval $\Delta\nu$ on light frequency ν. Besides

$$\frac{h\nu}{kT} \gg 1. \tag{1}$$

Then

$$\frac{dT}{dt} = -\frac{k v U_\nu \Delta\nu}{2c\rho} = -\frac{4\pi k h \nu^3 \Delta\nu}{c\rho v^2}\, e^{-\frac{h\nu}{kT}}. \tag{9}$$

Solution (9) is brought about in the follwoing manner

$$\Gamma^2 e^{b\frac{1-\Gamma}{\Gamma}} = t^* + 1. \tag{10}$$

Here $\Gamma = \frac{T}{T_0}$ (T_0 initial temperature) $b = \frac{h\nu}{kT_0}$

non dimensional time $t^* = \frac{4\pi h^2 \nu^4 k(\nu)\,\Delta\nu\, t}{k c\rho v^2 T_0^2 \exp\left(\frac{h\nu}{kT_0}\right)}$.

During big t^*, when $\Gamma \ll 1$, instead of (10) we have

$$\Gamma = \frac{b}{\ln t}. \tag{11}$$

III. Let us assume that the space illumination and the initial temperature of the medium does not depend on coordinates x, y, z. These conditions are not difficult to satisfy, for example, in a thin, but endlessly extended in two other directions parallel density layer, limited by two plates heated to a constant temperature T_1. Obviously

$$\frac{dT(t)}{dt} = \frac{1}{c\rho}\int_\nu \left[E_\nu(T_1) - \frac{v}{2} U_\nu(t)\right] k(\nu)\, d\nu. \qquad (12) \tag{12}$$

In (12), E_ν is actually determined only by radiation of the walls, which raises considerably the heat background in the thin layer. Let us examine two cases of equation solutions (12)

1. The size $\frac{h\nu}{kT} \ll 1$. Then the corelation (12) appears as following

$$\frac{dT}{dt} = \frac{4\pi k(T_1 - T)}{c\rho v^2} \int k(\nu)\, \nu^2 \, d\nu. \qquad (13)$$

Solving the equation (13), we obtain

$$T = T_1 + (T_0 - T_1)\, e^{-at}, \qquad (14)$$

where a has the same value as in (6).

2. The absorption indicator k does not depend from the frequency of light ν. In this case, instead of the equation (12) we have

$$\frac{dT}{dt} = \frac{2k\sigma}{c\rho}(T_1^4 - T^4),$$

whose solution may be written out in the following manner :

$$\frac{1}{4} \ln \frac{(1+\Gamma)(1-\Gamma_0)}{(1-\Gamma)(1+\Gamma_0)} + \frac{1}{2} \operatorname{arctg} \frac{\Gamma - \Gamma_0}{1 + \Gamma\Gamma_0} = t^*. \qquad (15) \qquad (15)$$

In the formula (15) $\Gamma_0 = \frac{T_0}{T_1}$, $\Gamma = \frac{T}{T_1}$ non dimensional time $t^* = \frac{2k\sigma T_1^3}{c\rho} t$,

For small t, when Γ is close to Γ_0, the correlation (15) is transformed into

$$\Gamma = (1 - \Gamma_0^4)\, t^* + \Gamma_0, \qquad (16) \qquad (16)$$

which is equivalent $T = \frac{2k\sigma}{c\rho}(T_1^4 - T_0^4)\, t + T_0.$

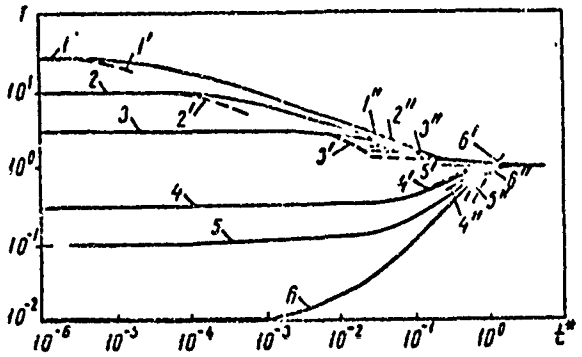
In the case of big t^*, when Γ is close to 1, out of the formula (15) it follows that;

$$\Gamma = 1 - \frac{2(1-\Gamma_0)}{1+\Gamma_0} e^{-4t^*}. \qquad (17)$$

Here $d = 2 \operatorname{arctg} \dfrac{1 - \Gamma_0}{1 + \Gamma_0}$. It is evident, if $\Gamma_0 \gg 1$, then $d \approx -\frac{\pi}{2}$;

if $\Gamma_0 \ll 1$, then $d \approx \frac{\pi}{2}$

Dependence of Γ from various Γ_0 - Curve figures correspond to various Γ_0



Зависимость Γ от t^* при разных Γ_0. Цифры у кривых соответствуют разным Γ_0:

1, 1', 1'' — 30; 2, 2', 2'' — 10, 3, 3', 3'' — 3; 4, 4', 4'' — 0,3; 5, 5', 5'' — 0,1; 6, 6', 6'' — 10^{-2}. Цифры без штрихов расчет по (15), со штрихом — по (16), с двумя штрихами — по (17)

On the drawing, a logarithmic scale indicates the dependence of Γ from t^*, in the presence of various Γ_0 obtained on the basis of the formula (15) (unbroken lines). Here are built in curves according to nearest formulas (16) and (17) (prime lines). From the drawing on can see that the range t^* in which the correlations (16) and (17) are reliable, with the decrease Γ_0 is widened for (16) and narrowed for (17)

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